

# 9

## Farming the Brackish Waters

*Probably the only parts of the sea which can be farmed are in inshore waterways and estuaries which are well protected from the open ocean. Although such areas are farmed in a few countries, they are completely neglected or even badly used in many parts of the world. Yet, when properly manipulated, they can produce larger quantities of animal protein than can farmland. This chapter discusses the fertility of brackish inshore waters, describes the species which are most suitable for cultivation in them, and suggests lines of research which should lead toward yields and profits in aquiculture.*

There are long stretches of coast about the world where land and sea are not so sharply distinct as they are at rocky shores; where, instead, the two merge gradually in an irregular and sometimes intricate edging of estuaries, sloughs, lagoons and mud flats, brackish swamps, and fringing islands. This transitional area where the land reaches out into the sea and the sea into the land is one of the most interesting of all marine ecosystems, and perhaps from a fishery viewpoint potentially the most valuable. In some places it is richer than the richest farm country, for it is lavishly fertilized with inorganic nutrients which the land is continually pouring into it.

Something about these brackish waters seems to be peculiarly necessary to many marine animals, something beyond the ordinary nutrient salts. What this essential principle or complex of principles is no one knows. Various lines of evidence point to organic nutrients which might be imparted to a large extent by the brackish flora of delicate, filamentous green and blue-green algae, which provide the niche and the nourishment for many kinds of organisms

from bacteria and protozoa up through herbivorous fishes and large invertebrates.

The brackish area is the habitat of valuable mollusks like oysters and clams. It is a kind of crossroads for fishes that divide their lives between fresh water and salt. Anadromous species like salmon and shad pause for a sojourn there before going out into the open ocean or on returning from the sea before going upstream to spawn. Many kinds of animals of the open sea are transient visitors there, entering and leaving at random in the course of their constant searching for food. Others, such as striped bass, spend much if not most of their lives there, and though they do go to sea annually to make excursions along the coast which probably increase in distance with age, they have to return for spawning. Still others, such as prawns, which are spawned only in the open sea, must go to the inside waters early in life. They are evidently carried thither during larval stages as the passive cargo of currents and tides, and if they fail to find an entrance they perish. Those that do get inside, reside there until time for their spawning migration.

Thus the brackish area is not only the home of its own fauna of year-round permanent residents, but is also a spawning ground for some species that come in seasonally, a nursery for others that drift in during planktonic stages, an occasional feeding ground for others that wander in and out at random, and a thoroughfare for still others that are migrating between river and sea destinations. With all this flow of life, the biological content of the brackish area is extraordinarily rich. And, being conveniently close to land, shallow, and well protected from the open sea, it is the most likely part of the sea to subject to cultivation.

True, hundreds of thousands of acres of these areas *are* cultivated in various parts of the world, mostly in Indo-Pacific countries. At the same time there are millions more that are not cultivated, or at least not developed to their full potential for the production of food. In many regions, fishermen treat the brackish inshore waters just as they do the open sea, hunting and gathering only the wild stocks. In doing this, they are making just as foolish use of environment as ranchers would if they were to use rich farmland for range country, or range country only for hunting wild game. In densely settled areas, people turn their sloughs and mud flats into unsightly dumping grounds for their rubbish. This is neglect of opportunity. What may be worse, because irrevocable, they often regard these areas as wasteland, to be filled in and thus "reclaimed" for agriculture, industry, or living space. This destruction of the unique brackish environment in order to create a relatively small piece of land is

not usually evaluated. Undoubtedly the need for land is important, but the consequent loss from devastation of marine animal protein resources may in some instances far exceed the benefits of the new land.

We might best judge the potential value of brackish waters by comparing the experience of peoples who have cultivated them with the experience of farmers. A good standard of comparison would be the production of domestic animals per unit area of farm land. Unfortunately, it is difficult to find suitable data because wide variation in the productivity of different soils and in the circumstances of production reduce the significance of averages. Statistics on production in brackish water ponds are even more elusive. At best, the available agricultural and aquicultural statistics can give us only a very rough basis for comparison, and as we shall see, they are not directly comparable. We need to know how much land it takes to feed the various kinds of farm animals. In other words, to what extent do they compete with human beings for food and space? How much do our meat and other livestock products cost, in terms of feed? How much space is required to produce that feed? The answers to those questions might best be derived from these estimates:

Under average agricultural conditions in the United States, the grain produced on one acre will feed enough livestock to yield around 21 pounds (dry weight) of protein food in a year.\* In comparing this figure with what is obtained from a brackish environment, we have to remember that a landsman has an advantage over a sea farmer in having behind him a tremendous accumulation of research in all the fields of science that touch his occupation—genetics, entomology, microbiology, biochemistry, and agronomy, to name only a few. What has the sea farmer that is comparable? Almost nothing. He is centuries behind the land farmer, and the results of his labors should be judged accordingly.

In many places the sea farmer does essentially little more than corral some animals into a prepared enclosure and hold them during a suitable growing period without feeding or fertilizing. Thus he allows them to be nourished by what comes naturally in the water. Although this passive treatment is called "culture," it is at best a primitive sort of culture, and of course the yields are not spectacular.

In the United States oysters are the only marine species which are grown commercially. Here, yields of 100 or 150 bushels an acre

\* This is about 37 per cent of the dietary allowance of protein recommended by the Food and Nutrition Board of the U. S. National Research Council for a moderately active American male weighing 70 kilograms (154 pounds).

are fairly common. These are 1.5 to 10 times as much as can be obtained from wild stocks on public grounds. Even so, they are only a fraction of what they might be when the science of oyster farming becomes further advanced.<sup>1</sup>

In places where marine aquiculture is practiced, yields vary widely according to location and types of soils, but perhaps mostly according to the amount of work and investment put into the enterprise. A good demonstration of what a brackish enclosure can yield with minimum labor and without special management has been made in an experimental pond at Bears Bluff Laboratory in South Carolina, U.S.A. Here Robert Lunz<sup>2</sup> found a stock of one species of fish (a drum, *Pogonias cromis*) to increase in weight 21-fold in nine months, and of the shrimp (*Penaeus setiferus*) to increase 14- to 15-fold in two months. He did not plant these animals, nor did he make much of any attempt at management, but admitted to his pond whatever entered naturally when he flooded it and gathered what was left when he subsequently drained it. On several drainings he harvested as shown in Table 9-1.

TABLE 9-1. HARVEST FROM THE BEARS BLUFF EXPERIMENTAL POND

Date Drained	Elapsed Time Between Drainings	Pounds of Fish Per Acre
8/29/47	6 months	147
7/7/48	10 months	162
8/24/49	13 months	194
4/28/50	8 months	83
11/27/50	7 months	20 *
5/17/51	6 months	180

SOURCE: G. Robert Lunz, "A Salt Water Fish Pond," *Contributions from Bears Bluff Laboratories*, No. 12 (Wadmalaw Island, S. C.: 1951), pp. 3-12.

\* Killed by cold.

In addition to the quantities given in the table, Lunz also gathered prawns and crabs, but owing to lack of help was usually unable to weigh them. On one occasion (May 1951) he measured 48 pounds of crabs per acre; on another occasion, over 40 pounds of prawns.

In Indonesia,<sup>3</sup> and also in the Arcachon Basin, France, commercial brackish ponds yield from 100 to 450 pounds of fish an acre (whole, wet weight). In Formosa, by contrast, they yield 800 to 1,200 pounds.<sup>4</sup> This wide difference may be attributed largely, if not entirely, to the fact that Formosans fertilize their ponds, and feed their stocks (whereas the others do not) and they cultivate much more intensively. Perhaps the ponds of Formosa come closest to achieving maximum production and are therefore the best basis of judging the potentiality of under-utilized brackish areas (Table 9-2).

It is not reasonable to draw from these data or from any of the literature on pond culture precise generalizations for universal application. However, this much it seems safe to say:

A properly constructed artificial brackish water enclosure can be handsomely profitable. At the very least, it will yield many times more pounds per acre than fishermen ever get from free fishing in the natural environment. With minimum care, taking whatever animals enter naturally, without fertilizing the water or feeding the stock, a brackish pond can yield more than half as much animal protein as an average acre of farmland supports. With the same kind of care that the farmland requires, that is, careful selection of stock, removal of predators, and fertilizing and feeding, a brackish pond can produce better than three times as much flesh as can an acre of land. This is by using present information. What might result if as much research were put into brackish farming as has already gone into agriculture, no one can say.

TABLE 9-2. PRODUCTION IN BRACKISH PONDS

Country	Pounds Per Acre				Total Edible Protein (Dry Weight) *
	Milkfish	Prawns	Other Species	Total	
Java (a)					
West .....	120	25	15	160	8.6
Central .....	100	25	15	140	7.6
East .....	180	70	30	280	15.1
Sumatra (b) .....	500	100	150	750	40.5
Celebes (b) .....	430	75	108	613	33.1
Lesser Sunda Islands (b)	414	69	138	621	33.5
Formosa (c) .....	958 †	?	?	958	51.7
India (Malabar Coast) (d)	—	—	—	900 †	48.6
Singapore .....	—	70-1,000 †	—	70-1,000	3.8-54.0
Philippine Islands .....	300 †	—	—	300	16.2
Cochin .....	—	1,200-1,500	—	1,200-1,500	64.0-81.0
France (Arcachon) ...	—	—	270	270 †	14.6

SOURCES: (a) W. H. Schuster, *Fish Culture in Brackish-Water Ponds of Java*, Indo-Pacific Fisheries Council Special Publication No. 1 (Bangkok: Indo-Pacific Fisheries Council, 1952). (b) Hasanuddin Saanin Sutan Larangan, *Aspects of the Inland Fisheries of Indonesia*, Indo-Pacific Fisheries Council Special Publication No. 2 (1953), 41-43. (c) Tung-pai Chen, *Milkfish Culture in Taiwan*, Chinese American Joint Commission on Rural Reconstruction, Fisheries Series: 1 (1952). (d) B. N. Chopra (ed.), *Handbook of Indian Fisheries*, prepared for the third meeting of the Indo-Pacific Fisheries Council, Madras, February, 1951.

\* Allowing 5.4 per cent of the weight of the whole fish. † A small volume of other species is included in this figure. ‡ Mostly mullet.

The heart of the job of brackish water fish culture is to control the ecosystem so as to improve the yield of desired species. Techniques of doing this must be adapted to the local fauna and environmental

conditions and to local economics and sociology. However, they always begin by closing off and improving a part of the environment. In the following paragraphs I shall quote brief descriptions of these operations as carried out in various parts of the world, in order to show what processes are involved.

In Arcachon on the Bay of Biscay there are about 600 acres of marine fish ponds which were artificially created by excavating and embanking suitable places in salt marches. They are flooded with sea water or brackish water controlled with sluice gates. Hickling<sup>5</sup> describes these ponds thus:

These appear as pleasant lakes and canals set in green meadows, separated from the Bay of Arcachon by a wide and strong embankment, pierced by numerous sluice gates. These were originally put up for the manufacture of salt; but it was soon noticed that fish, and especially mullets, which entered with the water, flourished and grew fast in the ponds. So salt making was gradually superseded by fish raising. The secret of full production in these ponds is the correct working of the sluices. Fish, and especially in this case the fry of mullets, and eels tend to swim against a current. Therefore, at neap tides, the sluices are opened very slightly so that a slow current of water flows out of the ponds. Fish fry are attracted by this current, and collect in the sluice gates. Then a fine meshed grill is placed in the gate to prevent their escape, and on the rising tide the small fish are swept into the ponds by the rush of water. This rush of inflowing water, of course, is also a signal for the larger fish, already growing in the ponds, to try to escape, but they are prevented by a long sleeve of netting, which is attached to a wooden frame fitting into the sluice, and through which the water is passed.

In Java, marine fish ponds, called *tambaks*, are built on estuarine low-level coastal flats, usually in places where the level is below that of the local mean spring tide. Schuster describes these as follows:

A tambak in its simplest form, common in West and Central Java, consists of a square or oblong sheet of water with an area of about 6 acres, from 1 to 4 feet deep. A small wooden or bamboo gate controls the in and out-flow of the water. Since there is tidal movement in those parts of Java, dikes 5 to 7 feet high are sufficient to protect the ponds against flooding.

Tambaks such as this are generally constructed by first digging a broad, shallow ditch along the sides of the plot, using the soil thus removed to build the embankment. Frequently, large quantities of soil are piled in ridges and hills in the centre of the pond to save the trouble of carrying the soil to the sides. Because of this practice ponds often are not simply an open sheet of water, but are divided into complicated patterns of strips of water and elevated parts by the long ridges of piled soil. If there is later a need to reinforce or heighten the embankment, soil is cut from the ridges, but only slow progress in bringing the ponds into correct shape is made in this way.

In other districts the ponds have been made so narrow that the removed soil could be deposited on the dikes without making use of a canoe or a

raft. In this way, wide sites of oblong ponds have been built with a length of a mile or more, but a breadth only of ten to twenty yards.<sup>6</sup>

Fenton Carbine writes of the Philippines ponds thus:

They are often built simply by surrounding suitable areas with dikes. Peaty clay and colloidal clay are considered the most desirable soil for pond bottoms and for building dikes; Nipa palm land is considered next best. Mangrove swamps are extensively used, but are expensive to prepare, for the trees must be removed and the wood is hard to cut and the stumps tenacious. Even so, the wood once cut, is in great demand for firewood and the bark for *cutch*, a product used for tanning fish nets and leather. The bottom of a pond is always higher than in mean low tide so that the pond can be completely drained.

All construction work is done by hand labor. In digging mud for building dikes, and in excavating or filling, a small spade-like instrument is used and the soil in the bottom of the pond, river, or estuary is removed in blocks. These are placed in a canoe, paddled to the construction area, and laid by hand in the spot where needed. Dikes are always built in a series of layers, each of which is about 2 feet thick. Each layer is allowed to dry for several days before the next layer is placed on top. Mangroves and Nipa palms are sometimes planted along the exposed sides of dikes to prevent damage by wave action, current, and other types of erosion. The bottom of a pond is prepared so that it drains readily toward the outlet, and large ponds may have several channels to facilitate drainage. Dikes vary in height, depending upon the tidal variation at each particular location.

Sluice gates, to control the inflow and outflow of the water in each pond, are usually built of concrete, although stone and wooden gates are still in use in many places.<sup>7</sup>

In Formosa, milkfish ponds, called *wun*, are built in series of 3 or 4 to 20 or 30, to serve various purposes, as water supply canals, nursery ponds, rearing ponds, and wintering ponds. Tung-pai Chen describes these as follows:

The water supply canal is of one to several meters in width and runs the length of the *wun* either on one side or between two rows of ponds. A sluice gate connects the canal with the sea, and other gates connect it with the ponds in the *wun*. In some *wun* of comparatively high elevation, mechanical pumps are set up on the dike for pumping water into the ponds to maintain the proper water level.

The nursery ponds are small ponds of less than one foot in water depth. The area of each is usually 100 to 200 square meters.

The rearing ponds are 3 to 4 feet in depth of water. They are in the shape of long ditches, with a width of about 10 to 20 feet. A bamboo wind-break is set up on the windward side (northeast) to ward off the cold wind during the winter.<sup>8</sup>

Like everything else about sea farming, designs of enclosures have evolved through generations of imperceptible steps resulting from occasional successes among many brave trials. In some regions the rate of this evolution has been held back by firmly established

orthodoxies. Therefore, the designs in use are not necessarily the best that could be devised. Among questions that deserve special study are these: What sizes, shapes and depths of enclosures would be optimal with given qualities of climate, soil, and water? How could sluices be made so as to control most effectively the biological content of an enclosure? Such problems should be put up to first class engineers to solve in collaboration with biologists. The design of ponds is of course an important subject for research. One which presses more immediately, however, concerns what goes into the ponds.

One of the most critical steps in brackish water farming is the proper selection of stocks. Very few species are suitable. Most marine animals could not survive the close confinement or the sharp fluctuations in weather that affect shallow water. Nor could many marine animals fully satisfy their own peculiar food necessities, some of which may be for organisms that occur only in the depths of the sea. Some species that could thrive in a brackish enclosure grow too slowly to provide frequent enough paying crops; others are too predaceous, will eat only fishes, including their own young, and therefore, even though fast growing, could not produce large enough crops for profitable farming. The value of a species for aquiculture depends on the extent to which it can meet the following qualifications:

1. Ability to feed, keep healthy, and grow in a brackish enclosure; tolerance of a relatively wide range of environmental conditions, particularly temperature and salinity
2. Fast growing, reaching a size suitable for market fast enough to produce frequent crops
3. Edible, fleshy, not so full of bones as to be troublesome to eat; fine flavored, marketable
4. Nonpredaceous, feeding on algae or on plankton
5. Breeding naturally in or near the brackish areas
6. Disease resistant

Animals which have proved to meet these requirements most perfectly are mullets (*Mugil* spp.), milkfish (*Chanos*), prawns, and oysters.

Mullets (*Mugilidae*) are among the most widely distributed of shore fishes. They occur on all coasts in the Pacific, Atlantic, and Indian Oceans, from South Africa, South America, and Australia northward to the British Isles, Cape Cod, Monterey, and northern Japan. There are more than 100 species in all; 13 of these are recorded from South Africa and 26 from India. Although most mullets have rather limited distribution, one form, the common grey mullet (*Mugil cephalus*), occurs all about the world in the tropics



and subtropics and even penetrates into temperate zones, an occasional specimen turning up as far north as Halifax, Nova Scotia. This species is pre-eminent among the few mullets which are suitable for cultivation.

Mullets are creatures of brackish or even fresh water. At maturity, however, they must go out into the open sea for their spawning season. The fry, produced at sea, find their way into the inshore environment, perhaps simply by passive drift, or perhaps by constant exploration along shore for openings and passages. It is in these passages that they are easily and cheaply collected in large quantities for stocking ponds.

Mullets are not carnivorous, but feed on organic material contained in the bottom mud or suspended in the water and on detritus of animal and plant origin. They grow to be about 30 inches long. They are particularly good subjects for fish farming because they are cheap to produce. They are farmed in the New Territories of Hong Kong, in Bengal, in Cochin, in the paddy fields of the Malabar Coast, and in the Arcachon Basin in France.

The milkfish (*Chanos chanos*) also is widely distributed, the only species known occurring along all coasts in tropical and subtropical latitudes of the Indian and Pacific Oceans, from southeast Africa to Australia, from New Zealand to southern Japan, and from Chile to the Gulf of California. Its environmental tolerances are considerable, though somewhat less than those of mullets. Milkfish is primarily a marine species. Although some individuals enter brackish and fresh water, they are not impelled to do so, and they seem never to enter voluntarily during their early youth. Consequently to farm milkfish it is necessary to capture the fry in the sea, a slow, difficult, expensive job. Once transplanted into an enclosure they do very well in their new environment in spite of the rigors of transportation in small earthenware jars, in which they suffer from heat and from oxygen depletion, and in spite of the sharp change of salinity which would be fatal to many other sea fishes.<sup>9</sup>

In the Philippine Islands there is a special fishery for milkfish fry, which are available almost all the year round in various regions. Some people rear the fry until they are 3 to 5 inches long, then resell them to other pond owners, who thus are able to produce three to four crops a year.

Milkfish grow fairly fast in ponds. In Indonesia, for example, they reach 1 to 1.6 pounds in eight months, and a stock of fish at that size is ready for a succession of croppings which extends over three or four months. If left alone, they grow to be at least 3 feet long. Like mullet, they are not carnivorous. The fry feed on an organic substance called *tai-aic* or *lab-lab*, consisting of decayed

algae, diatoms, protozoa, and bacteria. All this packs together in a mass having a jelly-like consistency, which lies as a layer on the bottom or floats in cakes at the surface. It is nutritionally rich, easily digested by the small fish, and its production and the regulation of its abundance constitute a most important part of the processes of milkfish culture wherever it is practiced. As the fish grow larger they feed upon somewhat coarser fare, which nevertheless continues to be composed of decaying algae, detritus, zooplankton, and diatoms.

Milkfish are probably more extensively cultivated than are mullets. In many parts of the Orient milkfish are an essential dish for ceremonial parties and often bring a very high price.

Of shrimp and prawns there are several genera and many species. They occur from the Arctic Ocean to the antarctic and in all types of environments from brackish swamps and creeks to the deep sea. They have great diversity of habit. Some shrimps live among sea grasses in inshore protected waters, others browse over the muddy bottom of deltas or on offshore banks. Some are wholly pelagic. Although relatively few species of shrimps are large enough, accessible enough, or abundant enough to be attractive commercially, those few can be exceedingly valuable.

Shrimp culture is highly successful in many parts of the Orient. In six test ponds in East Java the yields of prawns in pounds per acre per year came to 41, 330, 380, 470, 830, 230, and 250. This was in addition to the normal crops of milkfish. In Cochin, 1,200 to 1,500 pounds of prawns per acre are often harvested in addition to the rice crops.

The prawns of greatest interest for pond culture are the tropical and subtropical species belonging for the most part to the family Penaeidae. What gives them this particular interest is their habit of entering brackish inshore waters during infancy and remaining there for several weeks, which makes them conveniently accessible during that period. They feed low in the food pyramid, on plankton, decaying flesh, and organic detritus. As they approach maturity they return to sea for breeding. They are short-lived animals, most of them probably not surviving a year or two.

Prawns make a very profitable addition to a pond containing milkfish or mullet. It is not necessary to collect the larvae for planting since they enter incidentally when the pond is filled. Schuster says, "Millions and millions of larvae must enter . . . to secure a normal yield. Overstocking a pond with prawns is hard to imagine." A maximum number can be induced to come in by clever manipulation of the gates to the sluices for two or three days after filling.

In the Philippine Islands, fishermen collect prawn larvae by tying bundles of grass to a long heavy cord about 6 to 8 feet apart, which they string out at the edge of a mangrove thicket. At half-hourly intervals they lift out each bundle with a dip net, which collects the larvae that have gathered there. They put these into jars and sell them at the end of each day to pond owners for three centavos each. The larvae grow to catchable size within six weeks after entering a pond. Beginning about that time an urge to go to sea impels them to seek constantly for a way out, and since they can get through very small holes, many escape. Consequently, to get the maximum crop, a pond owner must harvest his stock of prawns early and intensively.

The success of prawn culture depends first of all on the supply of young, which varies greatly from one locality to another, certain rivers or channels consequently receiving more larvae than others. This may result from peculiarities of the current in the outside waters, which in large measure must direct the destination of the drifting larvae. Beyond that, the characteristics of the various rivers and creeks—rate of flow, fertility of the water, quality of the bottom soil, and the flora of the shore—must all exert some influence as to which of several directions the infants may take under such powers to navigate as they possess at that age.

Oysters are excellent subjects for pond culture. They are creatures of inshore environments, generally occur in depths shallower than 40 or 50 feet, and tolerate a wide range of saltiness from nearly fresh to almost undiluted sea water. There are many species of oysters, of which only certain ones are suitable for human use. They are distributed over the world in temperate and tropical latitudes. Some species are oviparous, other viviparous, but either way they spend their infancy as free swimming creatures, transported by tides and currents until they have developed to the point where they must settle to bottom. Then they cement themselves to the substrate and live out the rest of their lives permanently thus fixed. They filter large quantities of sea water through their gills, straining out their food, which consists of microscopic organisms. Oysters are peculiarly amenable to cultivation. Wild stocks are overcrowded, full of misshapen, stunted individuals, jammed with commensals, parasites, predators, and competitors. When fished intensively they quickly become depleted. On the other hand, if seed is carefully selected, planted in a protected environment with due consideration to proper spacing, and with periodic removal of predators, and if the adults are harvested at a proper rate, production can be sustained at a relatively high level. Although oyster farming is profit-

able where it is practiced, there are large areas where people fail to take advantage of the opportunity which their oyster resources afford. The fishermen, not knowing their great value, sometimes ignore them or merely gather from the wild stocks.

*Tilapia* is a genus of tropical fish, of which there are several species, native to Africa, belonging to the family Cichlidae. Since 1930, it has been introduced into ponds and paddy fields in Indonesia, Sumatra, Siam, Burma, Malaya, Formosa, the Philippine Islands, and the West Indies. Although *Tilapia* is a freshwater fish, it is included in this book because it is cultivated in brackish as well as in fresh water, and also because it serves as an excellent example of an exotic species which people have introduced with great enthusiasm without sufficient thought of the consequences. During the early stages of its introduction it did look like the perfect fish for tropical ponds. It lives peacefully with other species, feeding on algae, detritus, and plankton. Under favorable circumstances, individuals grow to weigh 30 ounces in a year. They mature at about three months of age. One writer said of them "All a farmer has to do is pour a can of *Tilapia* fingerlings into his pond and he is in the business as a fish farmer . . . The fish eats like mad, grows like mad and spawns like mad." It is that "mad spawning" which probably spoils *Tilapia* as a pond fish for human food, for populations tend to become so overcrowded that the members become stunted. This is so serious that the Food and Agriculture Organization of the United Nations no longer recommends it for pond culture. On the other hand, experiments in the Honolulu laboratory of the U.S. Bureau of Commercial Fisheries (Fish and Wildlife Service) show promise that *Tilapia* may be a suitable species to cultivate as bait for high seas tuna fishing.

Any research program about pond culture should make provision for seeking and testing other species which might be suitable. It does not seem likely, however, that many would be found and probably the center of interest would continue to be on mullet, milkfish, prawns, and inshore-dwelling mollusks, and on the environments which those species occupy.

True, brackish water farming has developed to a high level in oriental countries; but it is still practiced essentially by rules handed down from one generation to another, bound by tradition, and kept from advancing by the fact that there are wide gaps in knowledge about the animals, particularly about their life in the sea, and about the ecology of their inshore environment. No doubt these gaps would become narrowed with more centuries of experience, but they can be closed reasonably fast only by scientific research.

Part of this research would deal with a complex of problems regarding the spawning requirements of mullet, milkfish, and prawns. These animals must all leave the inshore waters at maturity and go to sea for spawning. Why? What elements of the open sea, what chemicals, what qualities of water, what light intensity, what quintessential foods are critical for their maturation and spawning? Could they possibly be induced, by some economical means, to spawn in a pond? Solving this problem would open the way to selective experiments and the development of strains of animals having particularly desirable qualities. All these questions demand physiological research under rigidly controlled conditions of a laboratory situated beside experimental ponds.

Another line of research should follow the natural histories of these animals, which are very poorly known. Where are the spawning grounds? What features of hydrography influence the subsequent distribution of eggs and larvae? What vagaries of environment affect their survival?

Here, the study of the sea habits of young milkfish is particularly important, for it should lead to improving means of locating fry, and of utilizing peculiarities of their behavior to attract and concentrate them. All this would have great practical value to brackish water farmers because collecting fry and transporting them is now laborious and expensive. It is hazardous, too, because people lose many fry while carrying them to their ponds in small earthenware jars. In Formosa, two men fishing steadily during two tides of one day will gather 50 to 70 fry, sometimes as many as 100, but seldom more. Because Formosans cannot supply their needs in this way, it is necessary for them to import from Indonesia and the Philippine Islands, where milkfish fry seem to be more abundant or at least more accessible. This too is expensive, adding greatly to production costs. Not only in Formosa, however, but wherever milkfish farming is carried on, people speak of the difficulty and cost of obtaining fry.

The search for spawning grounds and the study of the sea habits of the young fish require working in the outside waters on a seagoing research vessel. This vessel should also be engaged in determining how the various conditions and movements of the water affect spawning and the drift and survival of eggs and larvae. It should be fully equipped with instruments for making oceanographic observations, for collecting plankton, and for fishing, and its program should be supervised by a staff of competent oceanographers and biologists.

Oysters differ from other marine animals which are farmed in that they spend their entire lives in the inshore environment. Never-

theless, the problems involved in their cultivation are similar to those of the fishes and prawns. What influences the survival of their young, the production of seed, the rates of growth and mortality of oysters, and the abundance and habits of the predators? Oysters would make an excellent addition to a properly stocked pond, and these questions must be solved if there is to be a science of oyster culture.

There are many fundamental problems concerning the biology of the ponds. The Indo-Pacific Fisheries Council has posed one of the most important of these as follows: "It is highly desirable to evolve techniques for the assessment of the carrying capacity of ponds since a mistake along this point leads to high mortality and to the possible production of inferior quality fish. It is possible that this problem may be attacked on the basis of availability of food and space and such other criteria as may be found feasible."<sup>10</sup>

How do the various elements of environment influence the production of filamentous algae, flagellates, protozoa, and bacteria, and what conditions favor the formation of *lab-lab*, the substance on which milkfish, mullet, and perhaps also prawns feed? The fertility of ponds declines rapidly with continuous and prolonged use. How can it be replenished? Is it economically feasible and profitable to fertilize ponds? Could cheap, easily procurable artificial feeds be developed to supplement the natural supply?

What species are predaceous? How can they be kept out of ponds, or at least their numbers minimized? This is a problem which is particularly hard to solve in a marine pond, and therefore is usually neglected. It is equal in importance to the problem of keeping bears and wolves out of a cattle ranch. The research involved in predator control should begin with the biology of the predators to determine the weak points in their life history, and the peculiarities in their behavior of which advantage might be taken in devising control measures.

Pond culture research requires a laboratory. This must be located in a place where experimental ponds can be built, and which has easy access to the open sea. It ought to be in a country where there are extensive brackish water areas that are undeveloped, where there is a large population of people, and where a shortage of animal protein food is serious and appreciated. It could in fact be an environmental laboratory such as was discussed in Chapter 5, established in a tropical setting. It ought to begin on a small scale, centering its attention at first on studying the environments of the brackish in-shore area and of the immediate offshore vicinity.